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Anhydrous Ammonia Applications During Fallow for Winter Wheat Production[1]

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ABSTRACT

Anhydrous ammonia (NH_3) was applied at the rate of 67 kg/ha on 20 July and 8 September the summer after harvest and 15 May, 30 May, 15 June, 30 June, 15 July, 30 July, and 15 August the following summer during two 14-month fallow periods on Aridic Haplustoll and Torripsamment soils. The study was conducted to determine the ammonia application date during the 14-month fallow period which produced the soil water-soil NO_3-N distribution in the soil resulting in the maximum protein levels and grain yields of winter wheat (*Triticum aestivum* L.). Soil NO_3-N and soil water contents were determined to a 180 cm depth on each application date and at wheat seeding (15 September). In the Aridic Haplustoll soil, NH_3 had to be applied in the summer after harvest (over 1 year before wheat seeding) for maximum NO_3-N accumulation in the soil between 60 and 120 cm which produced the highest protein grain (14.5%) and the highest yield (3,269 kg/ha). In the Torripsamment, NH_3 applications between 15 May and 30 June the year of wheat planting produced highest protein grain (13.4%) and highest grain yields (2,688 kg/ha). However the optimum NH_3 application date to produce the desired NO_3-N accumulation in the 60 to 120 or 150 cm soil depths in the Torripsamment was not determined in this study.

Additional index words: **Application dates, Protein content, Grain yields.**

THE protein level of winter wheat (*Triticum aestivum* L.) grain produced in western Nebraska and western Kansas has been declining in recent years (3, 6). The decrease in soil N levels has been cited as one factor responsible for the lower protein levels (3). Research has also shown that the combined effects of rainfall > 1.25 cm during a 15-day period 40 to 55 days before maturity, available soil water and total soil nitrate to a 180 cm depth at seeding and maximum air temperature for a 5-day period 15 to 20 days before maturity accounted for 96% of the variability in protein levels of winter wheat grain produced in the plains area of Colorado and Nebraska (5).

The previous study (5) showed that when high NO_3-N concentrations were found in the soil below the 60 cm depth, the grain protein level was higher

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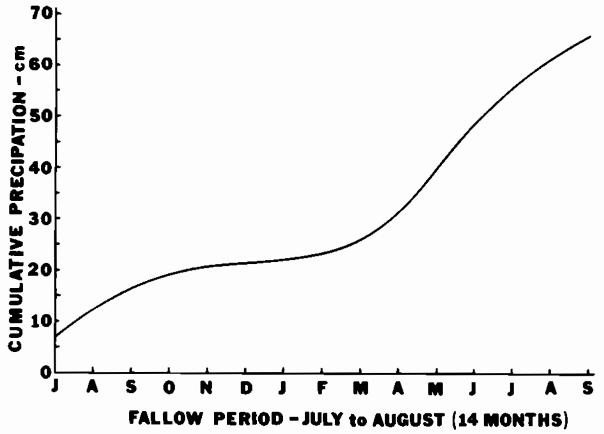

Fig. 1. Cumulative average precipitation by months from July to the second September of the 14-month fallow period, North Platte, Neb.

(regardless of total amount of soil NO_3-N) than when large amounts of NO_3-N were found in the top 30 cm of the soil. Generally a large portion of the soil water stored is below the 60 cm depth (2). Thus, we concluded that both the soil NO_3-N and soil water had to be in similar soil depths for the NO_3-N to effectively increase grain protein. However, in the semi-arid Central Great Plains, where a winter wheat-fallow rotation is widely used, the desired soil water-soil NO_3-N distribution relationship is difficult to obtain. Under normal conditions during fallow an average of 90% of the water is stored in the soil while only 45% of the natural NO_3-N is mineralized and moved downward in the soil (4).

We conducted this study to determine the effects of anhydrous ammonia (NH_3) application time during the 14-month fallow period on NO_3-N distribution in the soil at seeding time and the resultant effects of the NO_3-N distributions on grain yield and grain protein content.

METHODS AND MATERIALS

Experimental sites on an Aridic Haplustoll (Holdrege silt loam) on the Univ. of Nebraska North Platte Station Dryland Experiment Farm and a Torripsamment (Hersh fine sand) on a cooperator farmer's field 25 km southwest of the Dryland Experiment Farm were used during the 2 years the experiment was conducted. Average cumulative monthly precipitation during the 14-month fallow period at North Platte is presented in Fig. 1.

Individual plots received only one NH_3 application on each of the predesignated dates: 20 July and 8 September the summer after harvest and 15 May, 30 May, 15 June, 30 June, 15 July, 30 July, and 15 August the following spring and summer of the 14-month fallow period in a winter wheat-fallow rotation. The NH_3 was applied with a tillage machine with three V-blades, each 1.5 m wide and equipped to distribute the NH_3 uniformly along the under side of each blade. Blades were operated at a 10 to 15 cm depth at 4.8 km/hour. The NH_3 was metered to each plot through a piston action pump calibrated to apply the NH_3 at 67 kg N/ha. Plots were 9 m wide and 30 m long the 1st year, and 9 m wide and 23 m long the second year. The sites used the second year were not large enough for plots 30 m long so we used shorter plots to provide sufficient distance between replications so that the 4.8 km/hour ground speed could be reached and the NH_3 equipment would be operating satisfactorily before the actual plot was entered. A randomized block with three replications was used on both soils both years.

Samples for soil NO_3-N and soil water content were collected on each application date and at wheat seeding (15 September). Samples were 5.0 cm in diam and were taken with a hydraulic power sampler in the following increments: 0-15, 15-30, 30-60, 60-90, 90-120, 120-150, and 150-180 cm. Individual plots were sampled in three locations and composited. Samples for NO_3-N determination were air-dried and analyzed for NO_3-N by the phenoldisulfonic acid method. Soil water content was determined gravimetrically. Grain yield was determined from an area 2.4 m wide by 18 m long combine harvested when the field grain moisture content was approximately 13%. Grain protein content is reported as the product of the factor 5.7 times the percent total N in the grain as determined by the Kjeldahl-N procedure. All values reported are an average for the 2-year period. Nitrate distribution in the soil at seeding for the 20 July and 8 September NH_3 application dates was essentially the same within each soil type, therefore only one value was used to represent each datum point for these dates.

Table 1. Grain yield and protein content of winter wheat as affected by anhydrous ammonia application times during fallow on silt loam soil (2-year avg.).

Application time		Grain yield	Protein
		kg/ha	%
No application		2,755 a*	11.7 a
20 July	1st summer	3,293 bc	14.1 c
8 Sept.	1st summer	3,629 cd	14.5 cd
15 May	2nd summer	3,494 c	13.6 bcd
30 May	2nd summer	3,293 bc	13.9 bcd
15 June	2nd summer	3,494 c	13.6 bcd
30 June	2nd summer	3,494 c	13.3 bc
15 July	2nd summer	3,494 c	13.1 b
30 July	2nd summer	3,024 ab	13.2 bc
15 Aug.	2nd summer	3,091 b	12.1 a

* Values in the same column accompanied by the same letter are not significantly different (P = 0.05).

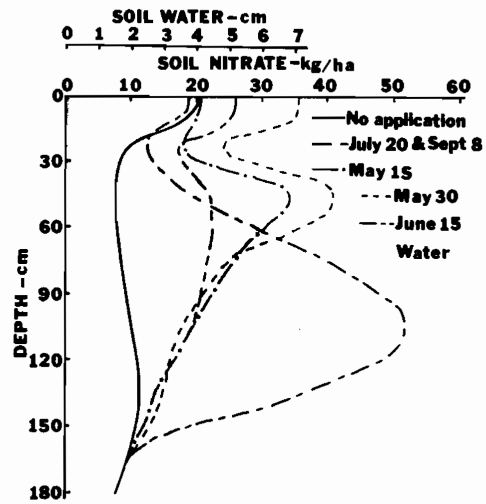

Fig. 2. Distribution of water and nitrate-N in the silt loam soil at wheat seeding for no application and five anhydrous ammonia application times resulting in highest grain protein levels (2-year avg.).

RESULTS AND DISCUSSION

Silt Loam Soil

Applying NH_3 at all dates to the silt loam soil increased NO_3-N in the soil at the end of fallow as compared with no application (Fig. 2 and 3). Differences in soil NO_3-N among application times ranged from 0 to 14 kg/ha. Soil fertilized after harvest (20 July and 8 September) contained approximately 60 kg/ha of NO_3-N before 15 May (the first application date the next spring). This 60 kg/ha of NO_3-N was very important because at the end of fallow soil fertilized on these dates contained over 90 kg/ha NO_3-N

Table 2. Grain yield and protein content of winter wheat as affected by anhydrous ammonia application times during fallow on fine sand soil (2-year avg.).

Application time		Grain yield	Protein
		kg/ha	%
No application		1,882 a*	10.7 a
20 July	1st summer	2,352 b	13.0 bc
8 Sept.	1st summer	2,621 bcd	12.5 bc
15 May	2nd summer	2,688 bcd	13.4 bc
30 May	2nd summer	2,755 d	13.6 bc
15 June	2nd summer	2,890 d	13.8 c
30 June	2nd summer	2,755 d	13.5 bc
15 July	2nd summer	2,890 d	13.1 bc
30 July	2nd summer	2,554 bc	12.8 b
15 Aug.	2nd summer	2,419 b	12.1 ab

* Values in the same column accompanied by the same letters are not significantly different (P = 0.05).

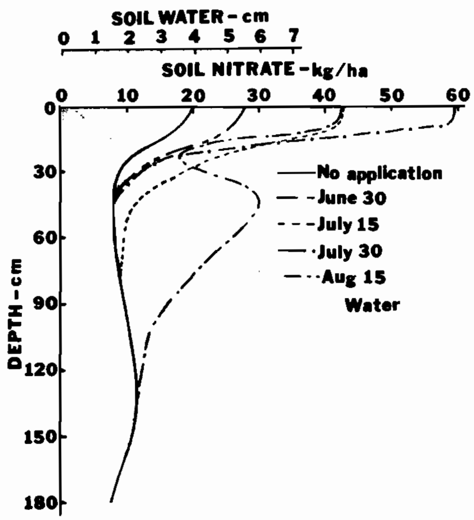

Fig. 3. Distribution of water and nitrate-N in the silt loam soil at wheat seeding for no application and four anhydrous ammonia application times resulting in the lowest grain protein levels (2-year avg.).

in the 60 to 120 cm depth, which was over 50 kg/ha more NO_3-N than was observed at a similar depth when NH_3 was applied at any other time (Fig. 2). The amount of NO_3-N in soil from the 60 to 120 cm depth for the other treatments ranged from 38 kg/ha for the 15 May, 30 May, and 15 June applications (Fig. 2) to 20 kg/ha for the 15 July, 30 July, and 15 August applications and the no application treatment (Fig. 3). These values are comparable to data collected at Alliance, Neb. (1).

Protein content of grain ranged from 11.7% where no NH_3 had been applied to 14.5% when the NH_3 was applied 8 September the summer after harvest (over 1 year before the wheat was planted) (Table 1). Grain protein content was closely related to total NO_3-N in the soil at the end of fallow ($r^2 = 0.83$). However the grain protein content-soil NO_3-N relationship improved ($r^2 = 0.95$) when only the NO_3-N in the 60 to 120 cm soil depth was used. Thus NO_3-N accumulation below the 60 cm depth was the most effective for increasing grain protein, while NO_3-N accumulation above 30 cm was the least effective.

When NH_3 was applied in the summer after wheat harvest, there was ample time for nitrification of the NH_3 and sufficient precipitation (Fig. 1) to move the

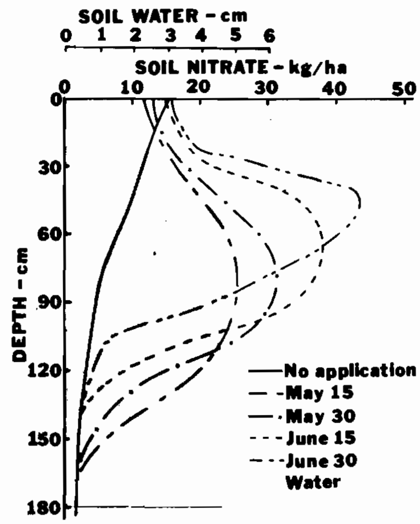

Fig. 4. Distribution of water and nitrate-N in the fine sand soil at wheat seeding for no application and four anhydrous ammonia application times resulting in the highest grain protein levels (2-year avg.).

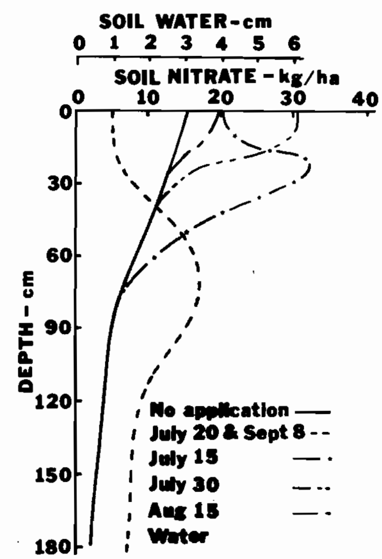

Fig. 5. Distribution of water and nitrate-N in the fine sand soil at wheat seeding for no application and five anhydrous ammonia application times resulting in the lowest grain protein levels (2-year avg.).

NO_3-N into the 60 to 120 cm soil depth. Approximately 13 cm of water were stored in the 60 to 120 cm soil depth. The amount of stored water decreased rapidly between the 120 and 150 cm depths with no indication of any water storage below the 150 cm depth. When NH_3 was applied after harvest the grain protein content was 2.8 percentage points higher than when no NH_3 was applied (Table 1). This increase in grain protein is highly significant and is attributed to a higher NO_3-N concentration in the soil at the 60 to 120 cm depth when NH_3 was applied after harvest as compared to the amount of NO_3-N present at the same soil depth when no NH_3 was applied. When the NH_3 was applied during the spring or summer before wheat seeding, the grain protein increased 2.2 percentage points over that when no NH_3 was applied.

This smaller increase in grain protein directly reflects the smaller amount of NO_3-N present with the soil water in the 60 to 120 cm depth.

Grain yields ranged from 2,755 kg/ha with no NH_3 application to 3,629 kg/ha when the NH_3 was applied on 8 September (the same date that produced the highest grain protein level) (Table 1). Grain yields obtained when NH_3 was applied the summer before wheat seeding averaged only 185 kg/ha less than the highest yield except when the NH_3 was applied on 30 July and 15 August which resulted in yields only 269 and 336 kg/ha, respectively, greater than when no NH_3 had been applied. Thus, for maximum grain yields there appears to be some advantage to applying the NH_3 more than 45 days before wheat planting on 15 September.

Fine Sand Soil

Ammonia at all application dates increased the total amount of NO_3-N in the sand soil at the end of fallow (Fig. 4 and 5). However, as expected, soil NO_3-N levels were generally lower than those in the silt loam soil. Nitrate-N increases between application dates ranged from 0 to 50 kg/ha. When NH_3 was applied between 15 May and 15 July soil NO_3-N accumulation was highest at the end of fallow (Fig. 4). Soil receiving NH_3 on 20 July or 8 September, after harvest, ended the fallow period with less NO_3-N in the 180 cm of soil than soil receiving NH_3 at any of the other application dates except 15 August (Fig. 5). These results are the opposite of that found in the silt loam soil. The low NO_3-N in the soil of the two after harvest application dates is believed due to nitrification of the NH_3 in the fall after application and downward movement of the NO_3-N in the soil with the winter and early spring precipitation (Fig. 1). The water holding capacity of the sand soil was approximately 40% less than that of the silt loam soil; therefore water and NO_3-N moved to depths greater than the 180 cm sampling depth. Nitrate-N movement below the 180 cm soil depth was indicated by the 8 kg/ha of NO_3-N in the 150 to 180 cm sampling depth which was not found in any of the other treatments (Fig. 5). Also, on 15 May (data not shown) soil in the 150 to 180 cm sampling depth contained 11 kg/ha NO_3-N, an amount not present in this depth of any other treatment. Thus as a result of fall nitrification and leaching evidently not enough NH_3 or NO_3-N was left to accumulate in the soil the following spring and summer.

Grain protein contents ranged from 10.7% without any NH_3 to 13.8% when the NH_3 was applied on 15 June (Table 2). These protein levels were very similar to those obtained on the silt loam soil, except for the 20 July and 8 September after-harvest application times. Protein content of the grain produced on the fine sand was also highly related to total NO_3-N in the 180 cm profile ($r^2 = 0.80$). Using only the NO_3-N in the 60 to 150 cm depth, the NO_3-N — grain protein relationship was higher ($r^2 = 0.88$) but did not increase like that with the silt loam soil. The 60 to 150 cm fine sand soil depth was used so that total available water (14 cm) would be comparable to that in the silt loam (13 cm). Increasing the depth to 180 cm or including depths nearer the soil surface did not improve the relationship. On all treatments on the fine sand soil the 60 to 150 cm soil depth contained less than 60 kg/ha of NO_3-N (Fig. 4) while on the silt loam with NH_3 applied after harvest, the soil contained over 90 kg/ha NO_3-N in the 60 to 120 cm depth. The NO_3-N level in the sand soil may have been too low to have the pronounced effect on grain protein observed on the silt loam soil. Therefore, apparently none of our application times resulted in the optimum soil water-soil NO_3-N distribution needed to produce high grain protein levels on fine sand soil.

Grain production was only 1,882 kg/ha without NH_3 and 2,890 kg/ha for both the 15 June (date with highest protein) and 15 July application dates (Table 2), which is only 135 kg/ha higher than obtained without any NH_3 on the silt loam soil. Grain yields were similar from all NH_3 application dates from 8 September of the harvest year through 15 July of the seeding year. However, there was a trend towards higher yields when NH_3 was applied between 15 May and 15 July of the seeding year. Ammonia applied on 20 July after harvest and 15 August the summer of seeding produced the lowest grain yields.

CONCLUSIONS

On the silt loam soil, applying NH_3 in the summer after harvest, more than 1 year before wheat seeding, resulted in the soil water-soil NO_3-N distribution relationship desirable for producing high protein grain as well as high grain yields/ha. This practice could be used to substantially increase protein levels of grain produced in the fallow-wheat rotation system.

With a fine sand soil NH_3-N applied the second summer resulted in the highest grain yields and grain protein levels. The optimum soil water-soil NO_3-N relationship was not obtained with the treatments in this study. However, NH_3 applied to fallow before 15 August, the year of wheat seeding, could significantly increase grain protein and grain yields on fine sand soil.

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